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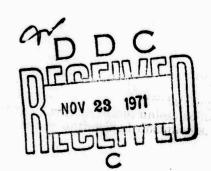|	
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I. TURBULENCE

A.   S. C. Lin and C. P. Wang

1. Strongly-heated grid turbulence

The insulation failure and short-circuiting difficulties reported in the last Annual Report (under Section III, Major New Facilities) has since been overcome by completely rebuilding the heating grid structure and by doubling the thickness of the folded-Inconel-sheet heating elements (i.e., from 0.010" to 0.020"). Study of homogeneous turbulence structure with large amplitude temperature-density fluctuations has been made using this new grid with electrical heating power in incremental steps up to 300 kilowatts. At this heating rate, the initial peak-to-peak temperature fluctuation amplitude at the exit plane of the grid was about 50% of the absolute mean temperature -- a fluctuation amplitude quite comparable to those encountered in typical hypersonically-generated wakes. Our results to date indicate that the temperature field fluctuation spectrum tends to establish itself in a more or less universal form rather quickly behind the grid (say, within a few tens of grid spacings). Preliminary results from this study will be presented at the Annual Fluid Dynamics Divisional Meeting of the American Physical Society, November 22-24, 1971, at San Diego, California.

2. High-temperature entrainment

We are continuing the development of experimental technique for generation of hot air bubbles for high-temperature entrainment studies, using the pulsed-arc method reported by S. C. Lin at the ARPA Workshop on High Temperature Entrainment, Riverside Research Institute, New York, N. Y., October 20-21, 1970. We have investigated different methods for initiating and terminating the pulsed arc, as well as the effects of different electrode geometry, discharge time constant, circuit impedance, etc., on the efficiency and homogeneity of energy deposition within the buoyant arc bubble. Our results to date indicate that while the bubble size and initial current distribution are indeed discharge-parameter-dependent, the sharpness of the laminar-turbulent interface, as well as the fluctuating temperature field structure within the turbulent hot air bubble, appear to be surprisingly insensitive to the initial conditions as soon as the bubble has undergone its own upward buoyant/entrainment motion and arisen a few times its initial diameter along the vertical direction.

We are also developing diagnostic techniques for quantitative statistical study of the fluctuating temperature field structure within such rising

hot air bubbles. Current results from these studies will be presented at the Annual Fluid Dynamics Divisional Meeting of the American Physical Society, November 22-24, 1971, at San Diego, California.

Publications

1. S. C. Lin, "Laboratory Simulation of High-Temperature Entrainment," Proceedings of the ARPA Workshop on High Temperature Entrainment, New York, N.Y., October 20-21, 1970.

2. C. P. Wang, "Motion of an Isolated Buoyant Thermal," Physics of Fluids 14, 1643 (1971).

3. C. P. Wang, "New Model for Laser Doppler Velocity Measurement on Turbulent Flow," Applied Physics Letters 18, 522 (1971).

4. C. P. Wang, "Measurement of Turbulence by Optical Mixing Spectroscopy," (submitted to the Physics of Fluids).

5. Shih-Chun Lin and S. C. Lin, "Homogeneous Turbulence with Large Amplitude Temperature-Density Fluctuations," (to be presented at the American Physical Society, Fluid Dynamics Divisional Meeting, San Diego, California, November 22-24, 1971.

6. S. C. Lin and C. P. Wang, "Generation of Isolated High-Temperature Thermals by Pulsed Arc Discharges," (to be presented at the American Physical Society, Fluid Dynamics Divisional Meeting, San Diego, California, November 22-24, 1971).

7. C. P. Wang and S. C. Lin, "Measurements of Mass Entrainment and Turbulent Mixing in Isolated Thermals," (to be presented at the American Physical Society, Fluid Dynamics Divisional Meeting, San Diego, California, November 22-24, 1971).

B.   C. H. Gibson

Measurements of turbulence and scalar mixing were carried out in a variety of systems and locations during the past year in order to investigate fundamental mechanisms over a wide range of Reynolds numbers, Prandtl numbers and Richardson numbers. Laboratory studies included temperature mixing in the water and mercury tunnels[1,2] and laboratory and gymnasium heated jets.[3,4,5] Field studies were made of the atmospheric boundary layer over the open ocean.[6,7,8,9] and stratified ocean turbulence and mixing in the Pacific Equatorial Undercurrent.[10] Data processing has been carried out using on-board or laboratory computer systems. Significant variation has been detected in "universal constants" of turbulence and mixing, which now appear to be weak functions of Reynolds number, anisotropy and/or stratification.

Publications

1. Gibson, C. H., John Clay and Steve McConnell, "Correlation of Strain Rate and Scalar Dissipation in Turbulent Mixing," (in progress).

2. Clay, J. P. and C. H. Gibson, "Turbulence and Temperature Measured in Mercury," Bull. APS Vol. 16 (1971).

3. Gibson, C. H., Steve O. McConnell and Carl A. Friehe, "Jet Turbulence and Temperature," Bull. APS Vol. 15, p. 1553 (1970).

4. Friehe, C. A., C. Van Atta and C. H. Gibson, "Jet Turbulence Structure," Bull. APS Vol. 15, p. 1553 (1970).

5. Friehe, C. A., C. W. Van Atta and C. H. Gibson, "Jet Turbulence: Dissipation Rate Measurements and Correlations," AGARD C.P. 93, No. 18 (London 9/71).

6. Gibson, C. H., "Measurements of Turbulence, Humidity and Temperature Over the Open Ocean from a Stable Platform," Proceedings of IUGG XV Gen. Assembly (Moscow, 1971).

7. Gibson, C. H. and P. J. Masiello, "Observations of the Variability of Dissipation Rates of Turbulent Velocity and Temperature Fields," Lecture Notes in Physics, 1971, Springer-Verlag.

8. Masiello, P. J. and C. H. Gibson, "High Reynolds Number Turbulent Dissipation Variability," Bull. APS Vol. 16 (1971).

C.   C. W. Van Atta

1. Current Work

We are assessing the feasibility of studying stratified wakes of bodies
(e.g. wake collapse) in our low speed wind tunnel. A heated grid used for
previous studies is being modified to produce a continuous vertical density
gradient in the tunnel. The general problem of attaining sufficient stratifica-
tion to produce observable dynamic effects on the fluctuating velocity fields
in air is being studied. The feasibility of building a continuous flow stratified
water tunnel is also under consideration. The design of suitable pumps is a
crucial factor here.

Experimental and theoretical work is continuing on selected aspects
of high Reynolds number atmospheric turbulence concerned with distinguish-
ing between older theories and those including the effects of intermittency
in dissipation rates.

Work is also continuing on the peculiar problems encountered in
measuring odd-order correlations using various techniques in turbulent
flows.

2. Major Accomplishments During the Past Year

Dr. T. T. Yeh and I have directly measured the scalar energy trans-
fer spectrum in decaying heated-grid turbulence, the first measurement of
this spectral function, which contains the essential physics of the mechanism
of spectral energy transfer between different wave numbers in turbulent
flow. This work included the first direct measurement of the triple correla-
tions between velocity and temperature fluctuations at different points in a
turbulent flow. The direct measurements are in good agreement with the
results of an alternate indirect method of estimating the transfer. This
work has not yet been prepared for publication.

Structure functions up to 14th order of the velocity fluctuations in
atmospheric turbulence have been measured and compared with the strongly
conflicting results of the original (1941) and modified (1962) Kolmogorov
theories. The predictions of the modified theory are very close to the
measured behavior. The probability density of the increments of the
fluctuating velocity is found not to be self-similar, contrary to previous
speculation and measurements by Dutton and Deaven.

A simple theoretical extension of Yaglom's recent work indicates that
the correlation between the velocity and scalar dissipation fluctuations in a
high Reynolds number turbulent flow may be an important quantity in
describing the structure of passive scalar fields.

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Our paper on the turbulent Ekman layer has finally been completed (reference 3 below). We plan no further work of this type at present, except possibly some further analytical and computer calculations on the theory of Ekman boundary layer.

Publications

1. Van Atta, C. W. and J. Park, "Self-Similarity and Inertial Subrange Turbulence," Proceedings of Symposium on Statistical Models and Turbulence, Lecture Notes in Physics, Springer-Verlag (in press).

2. Van Atta, C. W., "Influence of Fluctuations in Local Dissipation Rates on Turbulent Scalar Characteristics in the Inertial Subrange," Physics of Fluids 14, 1803 (1971).

3. Van Atta, C. W., D. R. Caldwell and K. Helland, "A Laboratory Study of the Turbulent Ekman Layer," submitted to J. of Geophysical Fluid Mechanics.

4. Van Atta, C. W., and W. Y. Chen, "Structure Functions of Turbulence in the Atmospheric Boundary Layer over the Ocean," J. Fluid. Mech. 44, 145 (1970).

5. Van Atta, C. W. and J. Park, "Higher-Order Structure Functions and Statistical Self-Similarity of Turbulence in the Atmospheric Boundary Layer over the Ocean," submitted to J. Fluid Mech.

D.   P. A. Libby

During the past year Paavo Sepri completed an extensive study, involving both theoretical and experimental work, of the turbulence produced by a heated grid in a low-speed wind tunnel. Of particular interest are the careful measurements of the space-time correlations of temperature; these data should be of interest to research workers concerned with models for the space-time correlations of electrons with applications to hypersonic wakes. Several publications should come from Dr. Sepri's dissertation.

Related research on space-time correlations of temperature is continuing, particularly in the wake of a single heated rod.

Publication

1. Libby, P. A., G. Baccaglini and D. R. Miller, "Heat Transfer to Cylinders in Binary Gas Mixtures," submitted to Phys. Fluids.

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E.   D. B. Olfe

Theoretical work on reflected or piston-driven shock waves with radiative transfer has been finished.   This work led to the completion of graduate student Fred Su's thesis in December 1970, and to the subsequent writing and acceptance for publication of the two papers listed below.   This research not only provides a better understanding of the coupling of the radiative transfer and gas flow, but it is also of use for interpreting shock-tube measurements on high-temperature gases for which radiative cooling is important.

Current work consists of completing a theoretical study of blast waves with transparent gas radiation.   Graduate student Gary Erickson is completing numerical calculations, which show good agreement with our analytical work.   All previous analytical studies of radiating blast waves have treated only the self-similar case, whereas we consider the realistic nonsimilar case.   Both our analytical work and our direct numerical calculations show that a point explosion with transparent radiation does not generally undergo a complete transition from the early-time "adiabatic blast wave" to the "momentum conserving shell" predicted by astrophysicists for application to supernovae.   In addition, the "momentum conserving shell" solution can apply to some laboratory blast waves produced by laser induced gas breakdown.

Our work on radiating blast waves has led us to an interest in the stability of such waves.   Rayleigh-Taylor instabilities may develop in the radiatively cooled dense shell behind the shock front, perhaps resulting in the "turbulent" envelopes observed in supernovae remnants.   We are initiating order-of-magnitude calculations to isolate an appropriate stability study for the radiating blast wave situation.

Publications

1. F. Y. Su and D. B. Olfe, "Radiative Transfer Effects on Reflected Shock Waves. I. Transparent Gas, " Phys. Fluids (1971), in press.

2. F. Y. Su and D. B. Olfe, "Radiative Transfer Effects on Reflected Shock Waves. II. Absorbing Gas, " Phys. Fluids (1971), in press.

F.   F. A. Williams

Research on oscillatory hypersonic reentry has now been completed, and that on turbulent reacting flows has not yet begun. The reentry studies led to an interesting and probably significant result, which will be described here in qualitative terms.

The objective was to investigate the effect of transient ablation processes on amplification of oscillations in angle of attack for a reentry vehicle. Specifically, the ultimate objective was to calculate from first principles the damping coefficient for oscillation of a vehicle and to observe whether ablation can cause this coefficient to become negative. It had previously been demonstrated, both theoretically and experimentally, that oscillatory injection of fluid into the boundary layer can indeed amplify angular oscillations of a vehicle, provided that a suitable phase difference between injection and oscillation is maintained. The study was aimed at ascertaining, from a model for the ablation process, whether the required phase difference can in fact be realized. No studies had previously been undertaken with the objective of calculating the phase difference during ablation.

The first step was to develop a model for steady-state ablation. Attention was focused on non-charring ablators, and an accurate model was developed for materials such as teflon, plexiglas and polystyrene. An exposition of the results and of the good agreement with experiment was published in Ref. 1. The same phsyics was then retained in a theoretical analysis of polymer regression-rate oscillations under conditions of oscillatory surface temperature. The results of this extended analysis were then married to a gas-phase flow-field analysis (both boundary layer and external inviscid flow) to finally obtain theoretically predicted damping coefficients. These later phases of the work are described in Ref. 2. The final result demonstrates quite unambiguously that transient ablation of teflon-like ablators cannot constitute a significant cause of dynamic instability under reentry conditions. This prediction, which contradicts earlier beliefs, arises through combined effects of two aspects of the ablation process. These effects are developed and explained physically in Ref. 2; they cannot be guessed at in the absence of the analysis given in Ref. 2. The conclusion to be drawn from the work is that instances of dynamic instability must be ascribed to some other phenomenon, such as ablation-modified transient separation and/or reattachment of the probably turbulent boundary layer on vehicles that have complex geometries (tail flares, etc.).

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References

1. G. Lengelle, "Thermal Degradation Kinetics and Surface Pyrolysis of Vinyl Polymers," AIAA J. **8**, 1989 (1970).

2. G. Lengelle, "Ablation Effects on Dynamic Stability of Reentry Vehicles," Ph. D. Thesis, University of California, San Diego, La Jolla, California, September 1971.

II. SHOCK TUBE

A. S. S. Penner and K. G. P. Sulzmann

1. **Significance of completed studies:** The completed studies on the reaction kinetics in NO-CO-Ar mixtures were presented at the International Symposium on Combustion at Salt Lake City, Utah, August 23-29, 1970 and were subsequently published.[1] The studies confirmed within a factor of two the pre-exponential factor and within an error of less than 5% the activation energy for the forward path of the <u>dry</u> CO-oxidation reaction $CO + O_2 \rightleftharpoons CO_2 + O$ which had been measured previously. Thus, the controversy raised about the earlier results has been resolved in favor of these data which have also been confirmed by new measurements.

2. **Research completed:** The shock-tube measurements of f-numbers for the α- and γ-bands of TiO have been completed and the results have been published.[2] These measurements were conducted on TiO formed <u>in situ</u> by reactions between $TiCl_4$ and O_2 in an excess of Ar and provide with the first absolute intensity determinations for the α- and β-bands of TiO.

3. **Research in progress:** Current shock-tube studies are designed to complete gf-value measurements for <u>weak</u> Fe_I-lines between 6270 and 6500 A of astrophysical interest on Fe_I prepared <u>in situ</u> by decomposition of $Fe(CO)_5$ in an excess of Ar as well as f-number measurements for the visible and infrared bands of FeO prepared <u>in situ</u> by reactions between $Fe(CO)_5$ and O_2 in an excess of Ar. This research will provide the first absolute intensity data for weak Fe_I-lines between 6270 and 6500 A and the visible FeO-bands. We expect the measurements on Fe_I to be completed by November 30, 1971.

For the intensity measurements of the infrared bands of FeO, we have completed and attached to the shock-tube a spectrophotometric

system which consists of a liquid helium cooled, copper-doped germanium detector and a calibrated black-body reference source arranged in such a way that the same optical geometry and the same transmission losses prevail for both, the band-intensity measurements and the calibration measurements. Room-temperature background radiation has been reduced by liquid nitrogen cooled windows in the shock tube and a liquid nitrogen background behind the shock-tube window opposite to the observation window. The measurements will be conducted by using liquid helium cooled broad- and narrow-band interference filters which we will calibrate in our laboratory. The calibration system consists of two modified Perkin-Elmer monochromators and a calibrated black-body standard.

Analytical expressions have been developed for the relative spectral absorption coefficient for the fundamental vibration-rotation bands of FeO which are based upon the "smeared rotational line" model; a computer program has been completed for the application of this model to the reduction of the measurement data. The relative absorption data obtained by this model as well as relative spectral absorption data based upon line-by-line calculations have been submitted for publication and are in print.[3] These calculations were performed with new data for the molecular constants and show that use of the new data results in an increase of 5% of the integrated band-emission when compared with data obtained by the older molecular data.

4. Plans for the next semi-annual period: After completion of the gf-value measurements for weak lines of Fe_I , simultaneous shock-tube measurements of the f-numbers for the visible and infrared bands of FeO will be conducted. A description of the calibration and measurement techniques used for the infrared bands will be published after we have completed the filter-calibration measurements. On the basis of currently available information relating to band intensities and band structure of TiH, it is likely that we will recommend additional intensity measurements for the $(^4\Pi(a) \rightarrow {}^4\Sigma)$-transitions of TiH between about 4500 and 5500 A.

<u>Publications</u>

1. K. G. P. Sulzmann, L. Leibowitz and S. S. Penner, "Shock-Tube Studies on Mixtures of NO, CO and Ar, " Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pa., pp. 137-146 (1971).

2. M. L. Price, K. G. P. Sulzmann and S. S. Penner, "Measurements of f-Numbers for α- and γ- Bands of TiO, " JQSRT 11, 427 (1971).

3. H. Fissan and K. G. P. Sulzmann, "Absorption Coefficients for the Infrared Vibration-Rotation Spectrum of FeO, " JQSRT (in print).

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III. MOLECULAR BEAMS

A.   D. R. Miller

Crossed molecular beam research has centered on the reaction $O + CS_2 = CS + SO$ which we reported on last year. We proceeded to make angular distribution measurements but found that oxygen atoms were reacting with condensed CS_2 on local surfaces, perhaps in the mass spectrometer itself. We rebuilt the crossed beam apparatus to separately pump the CS_2 and now find an SO product signal with a signal to noise ratio no better than one. We have made total scattering measurements and will be able to ascertain an upper limit to the reaction cross section, which will be much lower than previously reported. We are awaiting delivery of a new detection system which will give us a gain of 100 to further investigate this and other reactions.

Gas-surface interaction studies of argon and neon gas atoms on silver (111) crystals have been completed. Final results are in preparation for publication which show substantial qualitative agreement with classical theory in the epithermal (~ 1 eV) interaction regime. An invited review of this work will also be presented at the forthcoming AIChE Annual Meeting, 11/28/71. Measured properties of low energy helium (0.01 eV) atoms scattered from silver (111) demonstrated single phonon inelastic surface scattering which agreed remarkably well with two recent quantum mechanical theoretical treatments. This quantitative agreement is the first such result for inelastic atomic scattering from metal surfaces.

Current studies with new graduate students include measurement of slip effects and background diffusion in free-jet plume expansions, electron scattering cross sections for atomic oxygen, continuation of reactive crossed beam studies, reactive surface scattering involving O, O_2, and F_2 on metal surfaces. Calculations for a proposed study of collisional excitation of vibrational modes of CO_2 at high energies (~ 5 eV) and subsequent radiation from the excited CO_2 are also under way.

Publications

1. R. B. Subbarao and D. R. Miller, "Properties of 0.01 eV Helium Atoms Scattered Inelastically from Silver (111)," to appear in J. Vac. Sci. Tech. (1971-72).

2. Miller, D. R., G. Baccaglini and P. A. Libby, "Heat Transfer to Cylinders in Binary Gas Mixtures," submitted to Phys. Fluids.

IV. IONOSPHERIC PHYSICS

A. H. G. Booker

My research activities during recent months have covered mainly the following topics:

1. There is a necessity to find means for radiating HF waves at very low angles of elevation for long range radar purposes. This is usually done by placing the transmitter close to the ocean and building an elaborate ground screen on the beach. However it is also possible to achieve this objective by means of a long sloping site terminating in a flat plain (not necessarily sea water). Means for doing this have been worked in some detail in collaboration with the Rand Corporation.

2. A burning rocket creates a modification in the ionosphere, expecially at F region levels below the level of burnout. This modification has interesting effects on the propagation of HF waves. The character of this modification and its dependence on frequency and height has been studied, both theoretically and in relation to experiments. The work has been done in collaboration with a summer study organized by the National Academy of Sciences.

B. J. A. Fejer

Parametric instabilities in the presence of a magnetic field have been treated, with particular emphasis on electromagnetic waves of ordinary polarization excited parametrically by electromagnetic waves of extraordinary polarization (Fejer and Leer, 1971a). These latter types of instabilities are probably strongly affected by the inhomogeneous nature of the medium. The first step in attacking this problem was the development of a method of treatment of parametric instabilities in inhomogeneous media (Fejer and Leer, 1971b) which is particularly suitable for extension to electromagnetic parametric instabilities. Work about to be submitted for publication was also done on anomalous absorption due to scattering into plasma waves by ionospheric irregularities and on a suggested theoretical explanation of the many types of variations of the parametrically excited plasma line intensity observed at Arecibo.

Publications

1. Fejer, J. A. and Egil Leer,"Excitation of Parametric Instabilities by Radio Waves in the Ionosphere,"accepted by Radio Science, 1971a.

2. Fejer, J. A. and Egil Leer,"Purely Growing Parametric Instability in an Inhomogeneous Plasma," submitted to J. Geophys. Res. (1971b).

3. Fejer, J. A. , "The Variability of Plasma Line Enhancement in Ionospheric Modification Experiments," submitted to J. Geophys. Res.

C.   G. J. Lewak

The problem of reflection and refraction of electromagnetic waves at a plasma boundary, including weakly nonlinear effects was treated. Penetration of the second harmonic below the plasma frequency was also calculated. A paper on this is in preparation.

The phenomena of a single pulse echo in a mirroring plasma (for example the magnetosphere plasma) has been predicted in a preliminary investigations. Further work on more details of the new phenomenon is in progress.

Work is also in progress on the investigation of parametric excitation of waves in a plasma. In particular the extension of the single theory, linear in the pump amplitude, to the weakly non-linear case is being pursued.

Publications

1. Lewak, G. J.,"A Single-Pulse Echo Effect in a Mirror Plasma," submitted to J. Geophys. Res.

2. Lewak, G. J. and E. M. Zawadski,"Penetration to Second Order of an Electrostatic Field into a Warm Plasma," J. Plasma Phys. $\underline{5}$, 73 (1971).

3. Lewak, G. J. and Jide Ogunlana,"Stochastic Kinetic Theory and Turbulent Heating," submitted to J. Plasma Phys.

4. Ogunlana, Jide,"Functional Method for Some Nonlinear Problems in Plasma Physics and Thermonuclear Fusion," submitted to J. Plasma Phys.

V. LASER PHYSICS

A.   <u>S. C. Lin and C. P. Wang</u>

1. Strong thermal interaction

Experimental study of strong thermal interaction between a laser beam and an absorbing gas is being continued by a new graduate student, J. H. Morris, after the graduation of R. A. Chodzko in September, 1970. The immediate task undertaken by J. H. Morris is to try to construct a good quality, electrically-pumped, CO_2-laser beam using the MOPA concept (a mode-controlled master oscillator driving a power amplifier). The objective is to increase both the beam diameter and the power so that the interaction zone can be studied with better spatial and temporal resolution than was possible in Chodzko's experiment (where the Gaussian half width of the beam was only 1.5 mm).

2. Advanced laser technology

Various exploratory experiments and theoretical studies related to advanced laser technology and diagnostics techniques are being pursued. These include a continued development of a reliable noble gas ion laser source operating in the visible region at a CW power level of a few hundred watts for Raman scattering and other laser interaction studies (CW power level of about 35 watts has been reached at the time of writing of this report), magnetic containment for improving the generation efficiency of ion lasers, dark-current excitation of molecular lasers, improved method for laser doppler velocity measurement in turbulent flow, etc.

Publications

1. R. A. Chodzko and S. C. Lin, "A Study of Strong Thermal Interactions between a Laser Beam and an Absorbing Gas, " AIAA Journal, <u>9</u>, 1105 (1971).

2. C. C. Chen, "Kinetic Processes in Noble Gas Ion Lasers, " Ph. D. Thesis, University of California, San Diego, June, 1971.

B.   S. S. Penner

Self-induced transparency (SIT) was observed[1] in bound-free transitions of Cl_2 in pure Cl_2 and in Cl_2-He and Cl_2-Ar mixtures. Measurements of the time-dependent transmission of an intense Q-switched laser pulse at 3417 A through a cell of chlorine gas showed that the transmission increased above the values predicted by Beer's law. These measurements of increased transmission, characteristic of the SIT phenomena observed in bound-bound transitions, represent the first time that this phenomena has been observed in a bound-free transition. In addition, estimates for the effective collision diameters for Cl_2-Cl_2, Cl_2-He and Cl_2-Ar were made from measurements of the reduction of the SIT phenomena with increasing pressure.

References

1. R. C. Sepucha and S. S. Penner, "Observations of SIT in Bound-Free Transitions of Cl_2," submitted to Phys. Rev. Letters.

2. S. S. Penner, "Use of Lasers for Local Measurements of Velocity Components, Species Densities and Temperatures," AIAA 6th Aerodynamic Testing Conference, Albuquerque, N. M., March 1971, AIAA Paper No. 71-283.

C.   A. T. Ellis

It was reported earlier that both ruby and neodynium laser radiation had been modulated at frequencies up to 300 megahertz and 100 megawatt power levels. This optical radiation has now been absorbed in several liquids and solids in order to produce high level stress waves by thermo-elastic interaction. The resulting waves were observed and measured by a quartz transducer and oscilloscope with 0.3 nanosecond response time and also by a specially constructed Schlieren system with a 75 nanosecond exposure time using a high intensity xenon flashlamp and a Kerr cell shutter. Stress levels observed agreed approximately with theoretical values and ranged up to 10,000 psi in a compressive pulse with a plane wave front from the unfocused laser beam. The Schlieren system proved especially valuable for observation of both the shock wave fronts, the acoustic wave trains, and rupture of the liquid or solid due to the high stresses.

The optical modulation, however, resulted in poor waveform from the point of view of desiring a single frequency. An alternate approach was tried which removed this objection. It consisted of making an optical grating with a thick emulsion (949F) photographic plate using a gas laser and then bleaching the plate so that there would be no absorption but only a phase shift which depended on emulsion thickness. The laser beam was passed through this grating and a stress wave of sinusoidal space-wise intensity was generated and propagated in two directions perpendicular to the laser beam axis. Step functions of stress were also generated by using a simple transparent strip to mask the entering laser beam.

It therefore appears that the development of a high frequency high level source of stress waves for acoustic holography has been successful and it now remains to ascertain the resolution attainable by making the holograms.

During this report period the breakdown of a liquid from laser radiation has been studied and results are given in the publication listed below.

Another area of study of material breakdown from high energy photons has been initiated by the acquisition of a suitable lithium iodate frequency doubler for our ruby laser as mentioned in our last research proposal. At the time it was uncertain whether such a crystal could be obtained in this country since the first experiments were performed in Germany. Suitable accessories are now being constructed for this work.

Publication

1. M. P. Felix and A. T. Ellis, "Laser Induced Liquid Breakdown - A Step-by-Step Account," to appear in the Dec. 1, 1971 issue of Applied Physics Letters.

D.   W. Nachbar

Our work has been to complete the computational program for the stress and deformation arising from impulsive heating of homogeneous elastic solids, and this program as outlined previously is now finished. The stress-focusing problems that have been computed for the solid sphere (a) and the solid cylinder of infinite length (b) with a short-time-duration (less than characteristic acoustic wave time), ramp-type temperature rise. For cases (a) and (b), two types of boundary conditions have been considered.

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(i) the uniform solid with a stress-free surface

(ii) the uniformly-heated solid core in an unheated infinite medium of the same material.

These studies all show that tensile stress pulses of large magnitude and exceptionally short duration (of the order of nanoseconds) can be produced at the centerline in such problems provided that all of the theoretical asssumptions are met. The symmetry of the loading as well as the homogeneity are especially critical assumptions. It was intended to study cavitation damage mechanisms theoretically and experimentally if the stress fields pre-existent to cavitation can be computed and controlled.

Two difficulties have arisen in application of this analysis to the laser interaction, as has been shown by the experiments of Ellis and Felix on liquids. One difficulty is the filamenting of the laser beam in the absorbing media, leading possibly to energy absorption in the thin filaments that is very much larger than the averaged energy over the beam cross sections. The second difficulty is the inability to observe the focusing effects in the bubbles and to differentiate conclusively between preferential heating of impurities and possible focusing effects in PMMA solid.

Papers that report the results for the elastodynamic calculations are being written; the application of this work to laser interaction is still under investigation.

E.   G. A. Hegemier

The interaction of laser radiation with an absorbing solid is under study. The radiation is of the impulsive type, typical of a Q-switched ruby laser. The materials under consideration are those approximating temperature-dependent elastic and viscoelastic media. The focal point of the research is the character of the stress waves generated. This research is motivated by the relation of the laser radiation-solid interaction problem to the use of the laser as a wave generating device in the laboratory, to controlled fracture processes in industry, and to the effect of a radiation environment on certain aerospace structures.

Publication

1. Tzung, F. and G. A. Hegemier, "Stress Wave Generation in an Elastic Absorbing Half Space Subjected to a Cylindrical Beam of Impulsive Radiation, " in preparation.

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VI. PERSONNEL

Personnel involved in the above research areas are listed below.
Individuals listed as faculty members or as research scientists are
members of the Institute for Pure and Applied Physical Sciences.

Alfericff, Michael	Research Assistant
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